WHICH RESOLUTION FOR RELIABLE ECG P-WAVE ANALYSIS IN ATRIAL FIBRILLATION?

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Abstract: P-wave analysis is becoming more and more used to help indentifying patients at risk for AF. Particularly, precise measurement of P-wave duration is an important factor in determining the risk of atrial arrhythmias. However, the methods to extract P-wave duration must be precise and reliable. Automatic analysis of P-wave must take into account technical aspects, one of those being the bit resolution. The aim of this manuscript is to investigate the effects of amplitude resolution of ECG acquisition systems on P-wave analysis. Starting from ECG recorded by an acquisition system with a LSB of 31 nV (24-bit on an input range of 524mVpp), we reproduced ECG signal as acquired by systems with lower resolution (16, 15, 14, 13 and 12 bit). We found that, when LSB is of the order of 128 µV (12 bit), a single P-wave is not recognizable on ECG (figure 1, upper panel). However, when averaging is applied, a P-wave template can be extracted, apparently suitable for P-wave analysis. Results obtained in terms of P-wave duration revealed that at lowest resolution (from 12 to 14 bit) the error on P-wave duration estimation is important and could lead to misleading results. However, the resolution used nowadays in modern electrocardiographs (15 and 16 bit) lead to results rather similar to those obtained with higher resolution.

1 INTRODUCTION

Analysis of P-wave is becoming more and more used for gathering information about the predisposition of patients to atrial tachycardia and atrial fibrillation (Censi et al, 2007; Dilaveris et al., 1998; Hayashida et al., 2005; Ozdemir et al., 2004).

The focus on P–wave is justified by its being representative of atrial conduction: a longer and more fragmented P-wave is related to obstacles, blocks and defects which provoke atrial electrical path to change and which are considered responsible for the promotion of atrial tachycardia and fibrillation.

The interest in the analysis of the P-wave has increased in the last decades; different methods are used, from manual analysis based on visual inspection to automatic processing techniques, by which reliable, more reproducible and objective measures can be obtained. Indeed, manual analysis of P-wave allows to extract quantitative but operator-dependant parameters such as P-wave duration and qualitative parameters such as classification of morphological features (monophasic, biphasic, etc…). Signal processing techniques allow to obtain reliable and more reproducible quantification of P-wave duration, quantitative measures of P-wave morphology and quantification of other P-wave features not distinguishable by visual inspection (e.g. root mean square of the last 20 ms of the P-wave) However, even when P-wave is automatically processed, little care is paid to the technical specifications of the acquisition system, particularly to its amplitude resolution, i.e. the value of the less significant bit (LSB).

The aim of this manuscript is to investigate the effects of amplitude resolution of ECG acquisition systems on P-wave analysis. Starting from ECG recorded by an acquisition system with a LSB of 31 nV (24-bit on an input range of 524mVpp), we reproduced ECG signal as acquired by systems with lower resolution (16, 15, 14, 13 and 12 bit).

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2 METHODS AND MATERIALS

2.1 Real High Resolution ECG

We started from ECG recordings obtained by using the ActiveTwo system by Biosemi. This acquisition system provides a 24 bit A/D conversion over an input range of 524 mVpp; thus the LSB is 31 nV. In this work we analyzed 160 ECG recordings obtained from 10 patients (16 leads/patient).

2.2 Simulate Lower Resolution ECG

From 24-bit ECG signal, new files containing the ECG signal at lower resolutions were generated by rounding the ECG values to the nearest integer value. Particularly, we reproduced A/D conversion at 16 bit, 15 bit, 14 bit, 13 bit and 12 bit. This resolution yields to LSB values as reported in table 1, given the input range of 524mVpp.

Table 1: LSB values obtained using 12,13,14,15 and 16 bit over the input range of 524mVpp.

Number of bit	Value of LSB (mV)
16	8 µV
15	16 µV
14	32 µV
13	64 µV
12	128 µV

2.3 Quantification of P-wave Features

To evaluate the difference in P-wave features, we automatically quantified P-wave duration and morphology from P-wave template extracted by averaging technique using specific algorithms. Every lead signal was pre-processed and analysed to extract the average P-wave characteristic. The first step is to detect P-waves from the acquired signals P-waves. Secondly, a beat-by-beat linear piecewise interpolation was used to remove baseline wander, on each P-wave. Then, the averaging procedure is performed to obtain a P-wave template. Ectopic atrial signals or P-waves with excessive noise were excluded by conventional template matching of each P-wave, with an exclusion criterion of cross-correlation coefficient lower than 0.9 (cross-correlation threshold). The averaging procedure went on until 200 beats were included. If the residual noise level remained at more than 1□V even after averaging of 200 beats, averaging procedure continued until the noise level reached a value lower than 1 □V. If it was impossible, the lead was excluded from the study. Residual noise was measured in the isoelectric segment before the P-wave (TP track).

For each P-wave template, P-wave duration has been automatically calculated as the time between the onset and the offset of the P-wave. P-wave onset is computed as the first point, among 20 consecutive points starting from the beginning of the P-wave, higher than 3 times the residual noise standard deviation. Offset was analogously defined considering the first point, among 20 consecutive samples, starting from the end of the P-wave window and going backward, where the signal level rises above the same threshold.

Morphological parameters were extracted according to the Gaussian function decomposition described in (Uhley, 2001).

3 RESULTS

Figure 1 shows an example of the same P-wave as visualized using 12, 13, 14, 15, 16 and 24 bit. While the signals obtained at 15 and 16 bit are visually comparable to the highest resolution (24 bit), the lower resolutions seem not to be suitable for a P-wave detection and analysis.

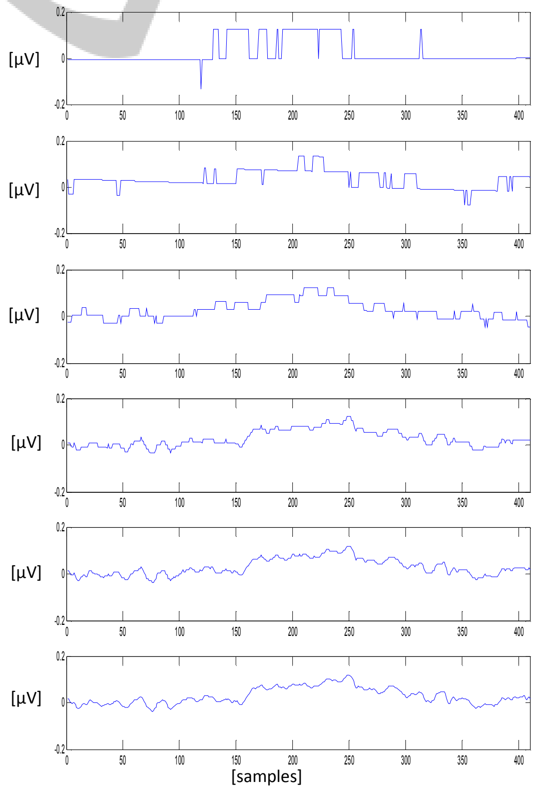

Figure 1: An example of the same P-wave as visualized using 12, 13, 14, 15, 16 and 24 bit.

When averaging is performed, the criterion of summing up at least 200 beats having a cross-correlation threshold higher than 0.9 (template matching) is no longer applicable at all resolutions. Indeed the resolutions of 14, 13 and 12 bit need a correlation threshold lower than 0.9 (until 0.5) for a template to be extracted using no more than 150 beats. Using these less restrictive criteria, a P-wave template can be obtained at all resolutions apparently suitable for P-wave analysis.

Figure 2 shows the P-wave templates obtained for the 12-bit and 13-bit simulated ECG, compared to the one obtained with the best resolution (24 bit, dashed line). 12-bit resolution appears to be quite different from the 24-bit ECG signal, in terms of onset, offset and fragmentation.

Figure 3 shows the automatic computation of P-wave duration, according to the algorithm described in the previous section. Since P-wave template at lower resolutions are quite more noisy than at higher resolutions, P-wave duration resulted to be significantly lower for 14 bit, 13 bit and 12 bit ECG signals.

Table 2 shows the percentage differences for P-wave duration measurements, for all bit resolutions tested respect to the highest resolution of 24 bit.

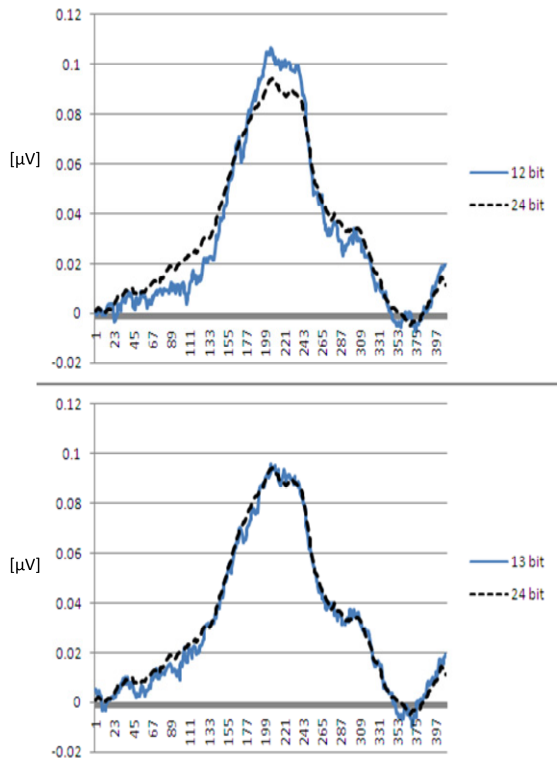

Figure 2: P-wave templates obtained for the 12-bit and 13-bit simulated ECG, compared to the one obtained with the best resolution (24 bit, dashed line).

Table 2: Percentage differences for P-wave duration measurements for all bit resolutions respect to the highest resolution of 24 bit.

Number of bit	Percentage difference
16	0
15	-1.2%
14	-6.4%
13	-15.2%
12	-18.1%

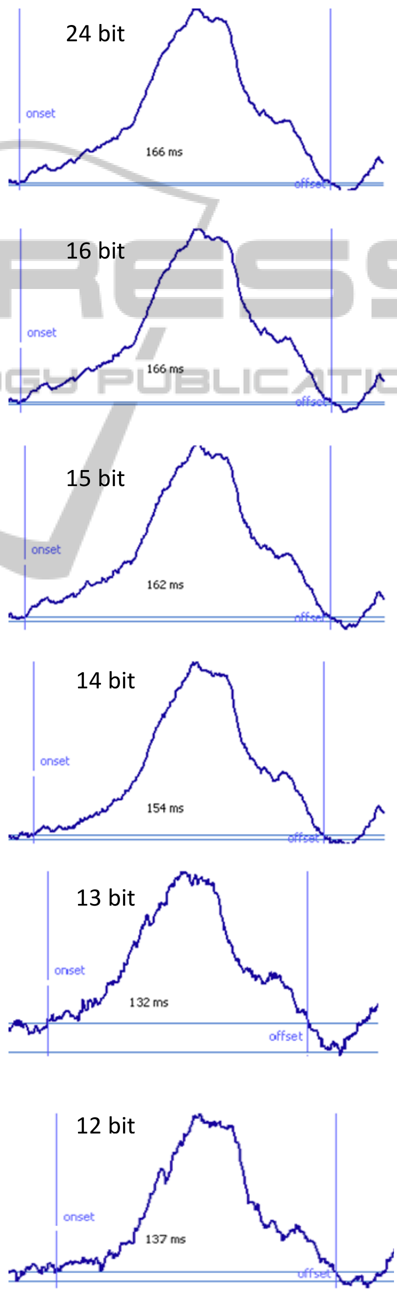

Figure 3: Automatic computation of P-wave duration for all bit resolutions.

As far as quantification of morphological features is concerned, we found that it was not significantly affected by the ECG resolution.

4 DISCUSSION

P-wave analysis is becoming more and more used to help indentifying patients at risk for AF. Particularly, precise measurement of P-wave duration is an important factor in determining the risk of atrial arrhythmias.

Some of these analysis is made manually by expert cardiologist (visual inspection). Automatic analysis is also performed, using converted digital ECG signals with variable number of bits. Commonly used electrocardiographs convert the signal using 16 or 15 bit, even if some analysis are made on ECG converted at lower resolution (12 bit). The LSB of such instruments, given an input dynamic of some mV, is in the range 5-15 μV.

Given the large number of experimental evidences on the association between P-wave prolongation and AF, Uhley suggested to design ECG machines in order to automatically calculate and display P-wave duration (Uhley, 2007). However, the methods to extract P-wave duration must be precise and reliable. Automatic analysis of P-wave must take into account technical aspects, one of those being the bit resolution. In this paper we investigate the effect of bit resolution of ECG signals on automatic P-wave analysis. We started from ECG signals acquired using a high resolution system having 24 bit resolution (corresponding to a LSB of 31 nV). We then obtained down-resolved ECG, simulating ECG acquisition using 16 bit, 15 bit, 14 bit, 13 bit and 12 bit. We found that, when LSB is higher than 100 μV, a single P-wave is not recognizable on ECG (figure 1, upper panel). However, when averaging is applied, a P-wave template can be extracted, apparently suitable for P-wave analysis. Results obtained in terms of P-wave duration revealed that at lowest resolution with LSB higher than 30 μV, the error on P-wave duration estimation is important and could lead to misleading results. In conclusion, the resolution used nowadays in modern electrocardiographs (about 5 μV) lead to results rather similar to those obtained with higher resolution.

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